ROCKY MOUNTAIN OILFIELD TESTING CENTER

MICROTURBINE PROJECT

Stacy & Stacy Consulting, LLC

March 31, 1998

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ABSTRACT

The Rocky Mountain Oilfield Testing Center (RMOTC) conducted a demonstration of gas-fired, integrated microturbine systems at the Department of Energy's Naval Petroleum Reserve No. 3 (NPR-3), in partnership with Stacy & Stacy Consulting, LLC (Stacy & Stacy). The project encompassed the testing of two gas microturbine systems at two oil-production wellsites. The microturbine-generators were fueled directly by casinghead gas to power their beam-pumping-unit motors. The system at well 47-A-34 utilized the casinghead sweet gas (0-ppm H2S) as fuel, and the casinghead sour gas (95-ppm H2S) was used at well 45-A-34.

Four areas of the microturbine-generator technology were evaluated: 1 . Utilization of casinghead gas as fuel. 2. Operation in an oilfield environment. 3. Power generation for beam-pumping-unit motors. 4. On-line availability. The demonstration proved successful in all areas. This report documents the equipment performance and the results of the Microturbine Project.

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FIGURE 1: STACY & STACY MICROTURBINE PRODUCTION TEST DATA

INTRODUCTION:

Lease operators handle the gas that is associated with oil-production wells in several ways. Gas is either piped to a gathering system for processing, shut in at the wellhead, or vented / flared. The most desirable option is to process the gas, but this is not always the most feasible. Shutting in the gas results in increased backpressure on the wellbore, which impedes production.

In stripper fields with pressure-depleted reservoirs, the venting of casinghead gas from oilproduction wells is a normal oilfield operation. Venting of the gas reduces backpressure in the well and the formation, which enhances production; however, venting wastes natural resources and presents environmental problems.

The Wyoming Oil & Gas Conservation Commission (WOGCC) provides guidance for the venting **of casinghead** gas from oil-production wells under Chapter 3, Section 40 of the WOGCC Rules and Regulations. The maximum venting rate for an "oil-production" well is 60 Mcfd. All "gas" wells require approval for venting.

Wyoming Department of Environmental Quality (DEQ) provides guidance for emergency releases of emissions from wells (both vented and flared) under Section 19 of the Wyoming Air Quality Standards and Regulations. Notification is required if regulated pollutants will exceed 5 tons from a single episode or 50 tons over a one-year period. The Air Quality Division is concerned with the effluent volume, time period of the release, H2S content, total S02 emissions, and emissionsminimizing efforts.

Section 21 of the Wyoming Air Quality Standards and Regulations provide guidance for emissions from normal operating procedures. If a well is constantly vented, it's considered an emission source. If there's no equipment on a production well, then it's permissible to vent the casinghead gas, provided it complies with WOGCC provisions which specify the 60 Mcfd maximum rate.

Utilization of microturbine systems can eliminate the casinghead-gas backpressure problems and minimize the emissions concerns of venting gas. Fired production equipment requires permitting under Section 21 of the Wyoming Air Quality Standards and Regulations as an emissions source, unless it uses less than 25 MM BTU / hr; then it would be exempt from air-quality monitoring. The estimated fuel consumption of a gas-microturbine system can be .377 MM BTU / hr, so it would be exempt as an emission source, provided its NOx and CO limits are not exceeded.

Best available control technology (BACT) is also addressed under Section 21 for venting / flaring operations. BACT is required if volatile organic compounds (VOC) are greater than fifteen tons or hazardous air pollutants (HAP) are greater than ten tons per year. Flaring and microturbine installations may qualify as BACT.

From a regulatory perspective, operation of a gas microturbine is preferred over venting, because of the resulting reduction in NOx and CO. The rated emissions of a microturbine system using natural gas can be 9 ppmv (corrected to 15% 02) for NOx and CO. From a lease operator's perspective, gas-microturbine systems can provide a means of utilizing waste gas to generate power for pumping units, and they can also generate revenue from the sale of excess electrical power.

MICROTURBINE-GENERATOR SYSTEM:

There are several manufacturers of gas microturbine-generators. The system that was tested was a Capstone Turbine Corporation "Charlie" unit. The remarkably-simple system is comprised of a generator, compressor, and a turbine that are incorporated on a single shaft. Filtered inlet air is compressed and then preheated, prior to mixing with gas and igniting in the turbine's combustion chamber. The expanding combustion gases are then routed back through the hot side of the heat exchanger to the exhaust stack.

The system incorporated a 28-kW turbogenerator, which produced a rectified-DC output. An inverter converted the DC-output to three-phase 208-VAC, which was transformed to 480-VAC. The 480-VAC was connected in parallel with the utility grid, instead of only providing power to the pumping-unit motor. Additional units could be incrementally connected in parallel to the grid for increased capacity. The rated output power of the tested system is 22.8-kW (at sea-level and 95 degrees F) but was derated to 23.7-kW at the field site, at 59 degrees F.

The controller was fitted with an RS232 connection for down-loading data and remote control operations, and a programmable-logic-controller (PLC) managed the control and operation functions. The system monitored and displayed real-time data, generator settings, fault history, operating history, cycle data, and configuration.

Automatic start-up of the Capstone micro-turbine is initiated from the display / control panel mounted on the front of the controller, by simply pressing the control-enable and start buttons. Power to start the system comes from the utility-grid connection, and the permanent-magnet generator is used as a motor during start-up. Utility power is used through the generator to drive the compressor / turbine until net power is available. A description of the start-up sequence follows:

1. The shaft is turned to 14,000 rpm within I second.
2. The burners light off within 5-10 seconds.
3. The turbine speed ramps up to 30,000-40,000 rpm while the hot components come up to **temperature.**
4. Once net generation begins the output ramps up to full load at approximately 1 kW / sec.
5. Shaft speed accelerates up to a maximum operating speed of 98,000 rpm.

The system incorporates many other engineering features. The compact, frame-mounted unit measures 4' L x 2' W x 4' H and weighs 325 pounds. The system's single-moving part (shaftmounted-generator / compressor / turbine) provides high reliability, and an air-bearing design allows the unit to operate without lubrication, which minimizes maintenance requirements. A prototype integrated-gas-compressor was not available for the field test.

WELL SELECTION:

Two low-volume gas-producing oil wells were selected for the Microturbine Project, 45-A-34 as the sour-gas supply (95-ppm H2S , and 47-A-34 as the sweet-gas supply (0-ppm H 2S). Both wells produce from the Second Wallcreek Formation from depths of approximately 3,000'. The wells are approximately one-quarter-mile apart, but the formation top for 47-A-34 is 89' down dip, in a different fault block. Flowing and shut-in pressures for the wells are approximately 15 and 75 psi, respectively. The surface elevation of 47-A-34 is 5,132' compared to 5,113' for 45-A-34.

SITE LAYOUT / EQUIPMENT:

Casinghead gas was piped to a two-phase separator (with mist extractor) and then routed to a skid-mounted gas compressor. The compressors vent and blow-down lines ran to a buried "drip" tank, and the three-inch discharge line from the skid's separator was buried out to the microturbine-system building where it swaged down to one inch prior to entering the building. A back-pressure regulator was installed in the gas supply line to prevent over-pressuring of the production equipment.

The compressor and two-phase separator were located near the wellhead, and the drip tank was **buried away from the equipment** to minimize personnel exposure to vented / free gas. The microturbine-generator was located a minimum of 75' from the wellhead, production equipment, **and gas compressor,** to comply with safety regulations.

A positive-displacement pump was installed inside the two-phase separator building for shipping liquids down the well's flow line. Heat trace and a propane-fired catalytic heater were used to protect the two-phase separator and gas-compressor skid from freezing.

TEST RESULTS:

Grilles were installed on all sides of the microturbine-generator buildings to provide inlet combustion / ventilation air and to minimize the possibility of gas buildup in the buildings, in the event of mechanical failure. The "open" environment did not present any apparent problems to the systems from the infiltration of either dust or precipitation.

Even though heat trace and catalytic heaters were used to protect the two-phase separators and gas compressor skids from freezing, the separator shipping line at 45-A-34 still froze during extremely cold weather. Operation of the microturbine system was however unaffected.

Following the commissioning / debugging period, a controlled test was established (3/13-20/98) **to evaluate the system's performance** under stable conditions. The microturbine systems were allowed to run in an unattended mode.

The gas compressor on 47-A-34 was down on 3/15/98 due to low suction pressure. The well's gas pressure has been dropping due to the blowing down of the reservoir's gas cap. It's interesting to note that the microturbine-generator continued to run during this time frame, off the gas that was stored in the compressor's volume tank. The low fuel consumption of the microturbine (7 to 8 Mcfd) may permit installation at marginal wellsites.

Fuel problems were encountered with the system on 47-A-34. Trouble-shooting indicated that liquids were being carried in the fuel line. When the 1" fuel connection was broken at the microturbine, liquids dripped out of the line, and when the line was blown out, a heavy mist was expelled for several seconds. The gas passed through two, two-phase separators and a mist extractor, but the liquids were apparently condensing in the 100' of three-inch poly line between the compressor and the microturbine-generator, due to extremely cold ambient conditions. The fuel problems would have been avoided with the proper placement of RMOTC's separator.

The output of the microturbine-generators exceeded 20 kW at each site during the course of the demonstration. The equivalent power consumption of the 20-hp pumping-unit motors is approximately 17 kW. If the systems had been installed for "stand-alone" operation, they could have easily powered the pumping-unit motors. The outputs of the units were reduced to 15 kw during the controlled test to optimize fuel consumption.

Over the controlled-test period, well 45-A-34 continued to stay on line with a 100 % availability, even though the well-gas supply was marginal. Well 47-A-34 went down once for approximately 4 hours on 3/19/98 due to liquids in the fuel line, resulting in an on-line availability of 98 %. Proper placement of RMOTC's separator would have prevented the down time.

PRODUCTION RESPONSE:

Increased production was anticipated, due to the drawing of gas from the wellheads, which reduces wellbore backpressure. Production tests were run on both wells during the Microturbine Project and compared to previous production figures. The data, presented in Figure 1, shows evidence of increased production from well 45-A-34; however, 47-A-34 did not show a response. It's intuitively apparent that the reduction of a well's annular backpressure is beneficial to production, but the brevity of the test may not have allowed the wells to stabilize. The blowing down of the reservoir's gas cap has probably also contributed to the slow production response.

FUEL-GAS ANALYSES:

During the controlled test, fuel gas samples were taken from both wells (on 3/18/98) from the compressor-skid outlets. Analyses of the major components follow:

Component	Unit	45-A-34	47-A-34
		"Sour" well	"Sweet" well
H_2S	ppm	120.000	20.000
H_20	# / MMcf	35.000	20.000
Air	mole %	3.174	1.556
Methane	mole %	61.113	85.667
C02	mole %	9.592	3.117
Ethane	mole %	7.750	4.333
Propane	mole %	9.431	2.745
Iso-butane	mole %	2.212	0.957
Normal-butane	mole %	3.479	0.614
Iso-pentane	mole %	1.311	0.301
Normal-pentane	mole %	0.936	0.146
Hexane+	mole %	1.004	0.563
Liquids	gallons / Mcf	5.652	1.665
Specific gravity		0.945	0.686
Heat content	BTUs / cu ft	1,322.226	1,110.760

The dynamics of blowing the gas cap down are becoming evident at NPR-3. The wells are located only one-quarter-mile apart, but show significant differences in their analyses. Well 47-A-34, which previously showed no H_2S, is now registering low quantities, and there is a 16% difference in heat content due to the heavier constituents in 45-A-34. The variance in the analyses of these sister wells, suggests the flexibility which is required of a microturbine-generator system to operate over a wide range of oilfield conditions. The water and liquids content also emphasizes the need for good two-phase separation.

SAFETY CONCERNS:

Several safety concerns were discussed by project personnel:

1. The maximum noise level was 105 decibels at the air inlet, inside a small, uninsulated, galvanized-steel building. Hearing protection is recommended inside the buildings.
2. The exhaust-stack temperature is estimated at 500 degrees F. Personnel should avoid contact with the exhaust stack and the microturbine housing.
3. Guards need to be installed over the controller's ventilation fans for personnel protection.

DESIGN IMPROVEMENTS:

Several design improvements were discussed by project personnel:

1. Integral gas compression is essential to reliable operation.
2. Fault records reflect down times, but not start times.
3. Display will be difficult to read unless relocated to a more ergonomic location.
4. Liquid knockout / separation is needed near the microturbine inlet.

POTENTIAL BENEFITS:

Commercialization of the microturbine technology for oilfield applications could provide great independence for oil producers, especially during an era of electric deregulation. The microturbine technology promises many potential benefits to the petroleum industry, including:

1. Reduction of vented / flared produced gas, which could alleviate emissions concerns.
2. Reduction of wellbore backpressure to enhance production.
3. Reduction of electrical power costs, through on-site electrical generation.
4. Reduction of capital expenditures, by eliminating the need for utility lines at remote sites.
5. Reduction of capital expenditures associated with controlling emissions.
6. Maintenance-cost reduction, compared with traditional reciprocating electric generators.
7. Generation of revenue, through the sale of excess electric power to utilities.
8. Utilization of waste gas for fuel.

CONCLUSIONS:

The microturbine-generator systems successfully met all testing criteria.

1. The equipment was able to bum unprocessed, casinghead gas directly from the well. The direct link does however present several challenges, the biggest of which appears to be the need for dry fuel gas. The systems appear to be very sensitive to the liquid content of the fuel gas, making the separation of liquids critical to reliable operation. Facilities modifications should be implemented for future testing, to facilitate the removal of liquids from the fuel stream at the microturbine-generator.

2. The implementation of a cutting-edge technology to a relatively-primitive oilfield environment was successful. The well-ventilated environment of the microturbine-generator building did not present any apparent problems to the systems from the infiltration of either dust or precipitation. The systems demonstrated a relatively-high tolerance for variances in fuel-gas pressure and liquid content.
3. The microturbine-generators could have easily powered the pumping-unit motors If the systems had been installed for "stand-alone" operation.
4. The equipment shows promise of very high reliability. Over the controlled-test period, well 45-A-34 claimed 100 % on-line availability, and well 47-A-34 demonstrated a 98 % availability, due to the test-site's facility constraints.
5. Under normal operating conditions, an increase in production should be expected, due to reduced wellbore pressure; however, the magnitude of the response will be dependent upon specific well parameters. Stacy & Stacy considers the microturbine technology to be commercially viable now, but still plans to continue the testing of the systems at NPR-3, as modifications are developed.

ACKNOWLEDGEMENTS:

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RMOTC is operated by Fluor Daniel (NPOSR), Inc., the Management and Operating Contractor **for the DOE's Naval** Petroleum and Oil Shale Reserves in Colorado, Utah, and Wyoming. Project work was directed by Project Manager, Michael J. Taylor, and project support was provided by Facilities Electrician, Bill Beahm, and by Engineering Technicians, Brian Meidinger, Dick Webb, **and Dan Kelly.**

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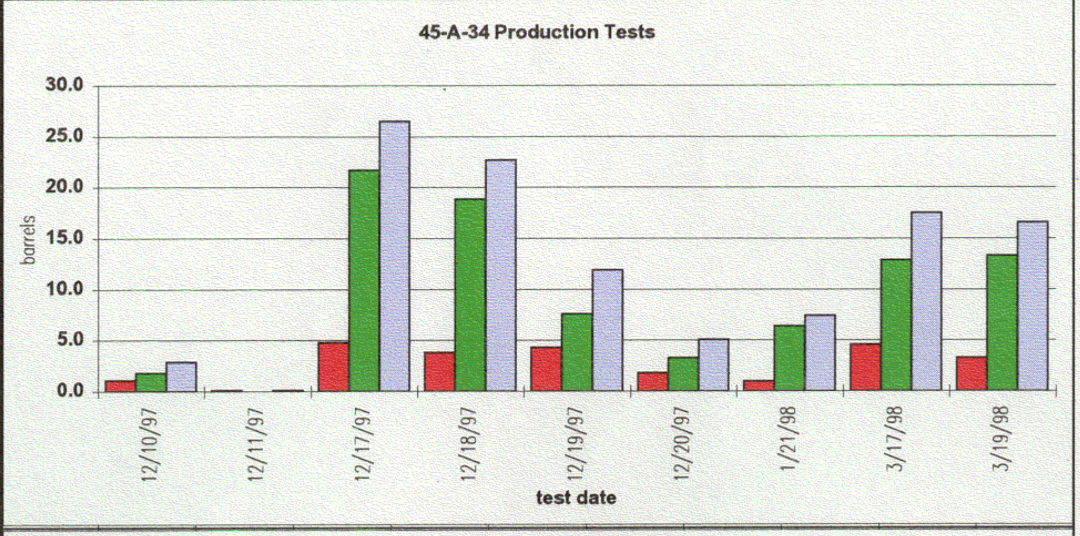
RMOTC's goal is to partner with the oil and gas industry to improve productivity, by field testing new petroleum technology, evaluating new equipment and techniques, disseminating information to industry, and conducting training. For more information, contact the Rocky Mountain Oilfield Testing Center, 907 North Poplar, Suite 100, Casper, Wyoming 82601; phone (888) 599-2200.

For information about Stacy & Stacy Consulting, LLC or for commercialization opportunities regarding this technology, contact Mark Stacy, President, 5300 Meadowbrook Dr., Cheyenne, Wyoming 82009; phone (307) 638-6091; fax (307) 638-6073.

STACY AND STACY MICROTURBINE PRODUCTION TEST DATA

45-A-34 Test Date	Oil (bbl)	Water (bbl)	Total (bbl)
12/10/97	1.1	1.8	2.9
12/11/97	0.1	0.0	0.1
12/17/97	4.8	21.7	26.5
12/18/97	3.8	18.9	22.7
12/19/97	4.3	7.6	11.9
12/20/97	1.8	3.3	5.1
1/21/98	1.0	6.4	7.4
3/17/98	4.6	12.9	17.5
3/19/98	3.3	13.3	16.6



47-A-34 Test Date	Oil (bbl)	Water (bbl)	Total (bbl)
12/8/97	6.6	89.0	95.6
1/17/98	3.4	80.6	84.0
1/18/98	3	76.5	79.5
2/5/98	6.4	74.0	80.4
2/6/98	6.1	78.7	84.8
2/7/98	3.4	80.5	83.9
3/7/98	4.8	93.3	98.1
3/8/98	4.0	79.4	83.4
3/20/98	7.7	71.2	78.9

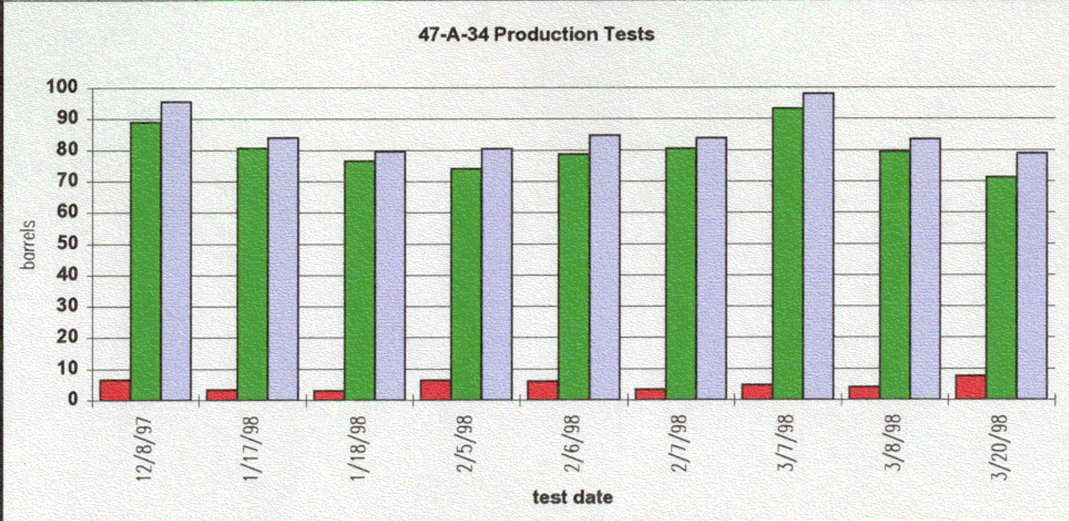


FIGURE 1

Figure 1